Loads Produced by a Suited Subject Performing Tool Tasks Without the Use of Foot Restraints

Sudhakar L. Rajulu and Jeffrey Poliner,
Lockheed Engineering & Sciences Company
Houston, Texas

and
Glenn K. Klute,
Lyndon B. Johnson Space Center
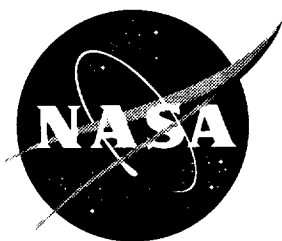*Houston, Texas*

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ACRONYMS

AMTI   Advanced Mechanical Technology, Inc.

ANOVA   Analysis of variance

EMU   Extravehicular Mobility Unit

ET   Endurance task

EVA   Extravehicular activity

HPPT   Handrail push/pull task

HST   Hubble Space Telescope

JSC   Johnson Space Center

MANOVA   Multivariate analysis of variance

MTT   Maximum torque task

NASA   National Aeronautics and Space Administration

PFR   Portable foot restraint

PTT   Power tool task

ACKNOWLEDGMENTS

1. INTRODUCTION

1.1 Background

Due to an increase in the number of extravehicular activities (EVAs) which astronauts will be performing in the coming years, NASA is interested in determining the capabilities of a suited astronaut working in a weightless environment.

Traditionally, a portable foot restraint (PFR) holds an astronaut involved in EVA tasks in position. The PFR provides adequate restraint to counter the forces generated from the use of a wide variety of powered and non-powered EVA tools. In certain situations, it may be advantageous to perform operations while free floating. This would save EVA time by not requiring the PFR to be set up. In those situations, the astronaut has to grasp the EVA handrail in one hand and perform the task with the other.

Engineers at NASA have done some work investigating the capabilities of suited astronauts to perform certain tasks while in foot restraints. However, very little information is available concerning their abilities to perform duties without the use of foot restraints. In addition, there is interest in gathering information concerning the loads transmitted to the EVA handrail when performing this type of task.

1.2 Brief Description of Study

The intention of this study was to examine the loads produced by a suited subject performing several EVA tasks with a single EVA handrail and no foot restraints.

1.3 Purposes of Study

Specifically, the purposes of this investigation were to:

1. Determine the amount of torque which can be produced by a suited subject in a weightless environment without the use of foot restraints.

2. Measure the loads produced on the supporting hand while performing various tasks in zero gravity without the use of foot restraints.

3. Determine differences in the loads produced on the supporting hand while performing various tasks between individuals' dominant and non-dominant sides.

4. Determine the effect of direction of tool rotation (clockwise vs. counter clockwise) on maximum torque production and supporting hand forces.

5. Examine the feasibility of using a power tool in a weightless environment without the use of foot restraints.

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1.4 Descriptions of Tasks Investigated

During an EVA, an astronaut uses various tools to accomplish a variety of tasks. In general, the astronaut uses standard tools that are modified to accommodate the equipment used in the Shuttle or proposed Space Station. The most commonly used tools are wrenches of various shapes. For highly repetitive tasks, efforts are under way to develop and use battery-powered tools.

In this study, four tasks were investigated: a maximum torquing effort with a wrench; a sustained torque with a wrench; the use of a battery-powered tool; and pushing and pulling an object normal to the work surface. Each of these is explained briefly below and in more detail in the following sections.

1.4.1 Maximum Torque Task (MTT)

This task examined the use of a wrench-type tool to produce a maximum isometric torque on a test fixture. Assistants positioned the operator at the work surface. The operator held a wrench in one hand and exerted a maximal isometric effort in a direction parallel to the mediolateral axis of his body. His other hand grasped an EVA handrail to the side (figure 1). Appendix A contains a description of the EVA handrail.

1.4.2 Endurance Task (ET)

The operator applied a sustained effort with a wrench in an angular direction parallel to the plane of his body. The other hand grasped an EVA handrail. The task was similar to that of the MTT.

1.4.3 Handrail Push/Pull Task (HPPT)

The operator applied a maximal force on an EVA handrail, in a direction normal to the work surface. His other hand grasped another EVA handrail nearby (figure 2).

1.4.4 Power Tool Task (PTT)

The operator used the Hubble Space Telescope (HST) power tool to loosen and tighten bolt fasteners. One hand held the tool and the other hand grasped the EVA handrail (figure 3). A description of the HST power tool can be found in Appendix A.
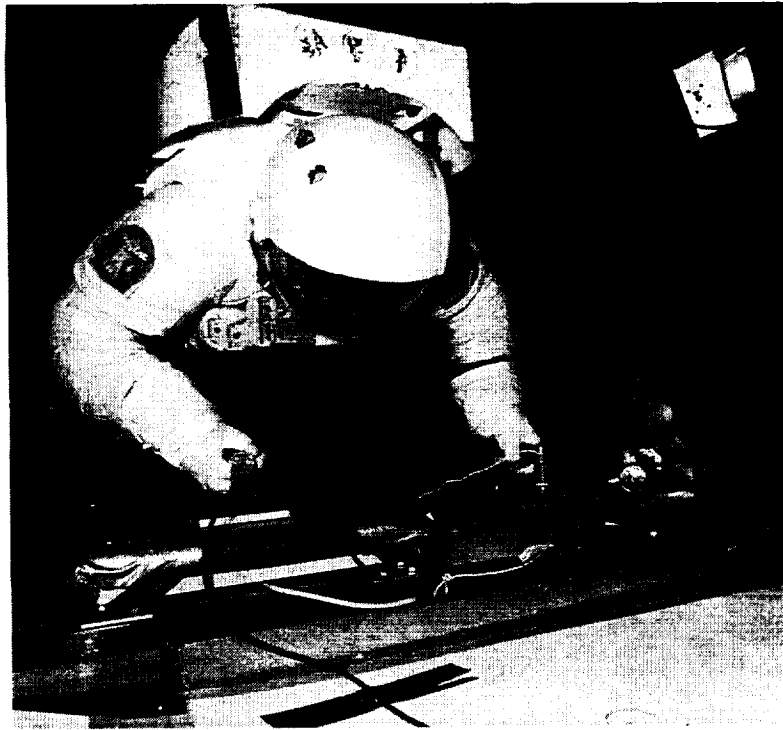
Figure 1. Picture of a suited subject performing the maximum torque task.

Figure 2. Picture of a suited subject performing the handrail push/pull task.
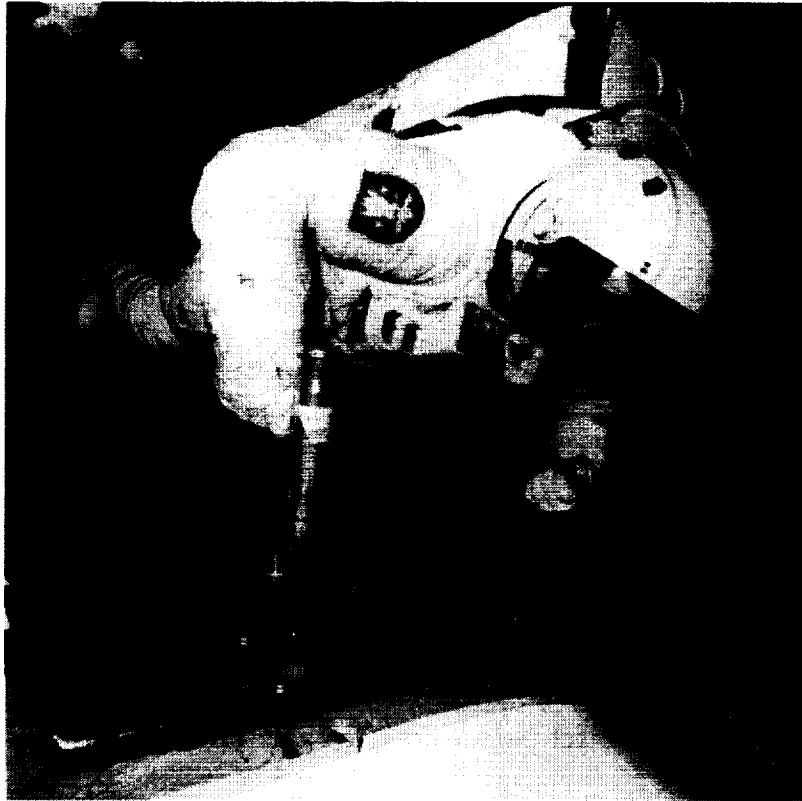
Figure 3. Picture of a suited subject performing the power tool task.

2. GENERAL METHODOLOGY

2.1 Subjects

Six male subjects participated in this study, including four astronauts and two non-astronauts. All were experienced in performing strength tests while wearing pressurized suits. The subjects had passed an Air Force Flying Class III physical examination and had taken the physiological training to qualify to participate in reduced gravity experiments. Their heights ranged from 162 cm to 180 cm with a mean of 175 cm and their masses varied from 61 kg to 77 kg with a mean of 70 kg. Although all were right-handed, both hands were tested in the study.

2.2 Apparatus

2.2.1 KC-135 Aircraft

Tests were conducted aboard NASA's KC-135 aircraft. This is a modified jet that is capable of flying a parabolic arc with a vertical acceleration equal to the acceleration due to gravity. Thus, during the arc, passengers and equipment within the plane experience virtual zero gravity. Each parabola lasted approximately 25 seconds. A flight consisted of 40 parabolas.

2.2.2 Equipment Setup

Figure 4 shows a photograph of the work site arrangement. A unistrut framework, approximately 190 cm by 55 cm, was attached to the aircraft floor. An AMTI (Model #OR6-6-1000, Advanced Mechanical Technology, Inc., Newton, MA) force platform was placed at the center of the frame. An EVA handrail was bolted to the center of the force platform. On one side of the EVA handrail were two 7/16" (1.11 cm) bolt heads, located 61 cm (24 in.) from the center of the forceplate. One was tightly fastened and the other could be turned with a pre-set resistance. On the other side of the EVA handrail was another bolt head, attached to a spring, giving a 34 N·m (25 ft-lb) resistance at an angle of ±45°. Another EVA handrail was attached to the framework on this side. During the push/pull study, the subjects grasped this EVA handrail and applied forces to the EVA handrail bolted to the forceplate. An instrumented torque wrench (Model #1150-200, GSE, Inc., Farmington Hills, MI) was used to measure the torque output. The wrench had two padded handles, located at 24.8 cm (9.8 in.) and 8.9 cm (3.5 in.) from the tool end.

Amplifiers (Model #2120A, Measurements Group, Raleigh, NC) for the four triaxial load cells in the force platform gave outputs of three orthogonal components of force and three orthogonal components of moments. The forceplate's coordinate system was such that, with the subject positioned as in figure 5, the Y-axis was parallel to the longitudinal axis of his body, the X-axis corresponded to the mediolateral axis of his body, and the Z-axis was perpendicular to the coronal plane of his body. The six force platform signals and the analog output from the instrumented torque wrench were sampled digitally by a data acquisition system at a rate of 250 Hz. A video camera was positioned nearby to record the study qualitatively.

Figure 4. Photograph of work site arrangement.
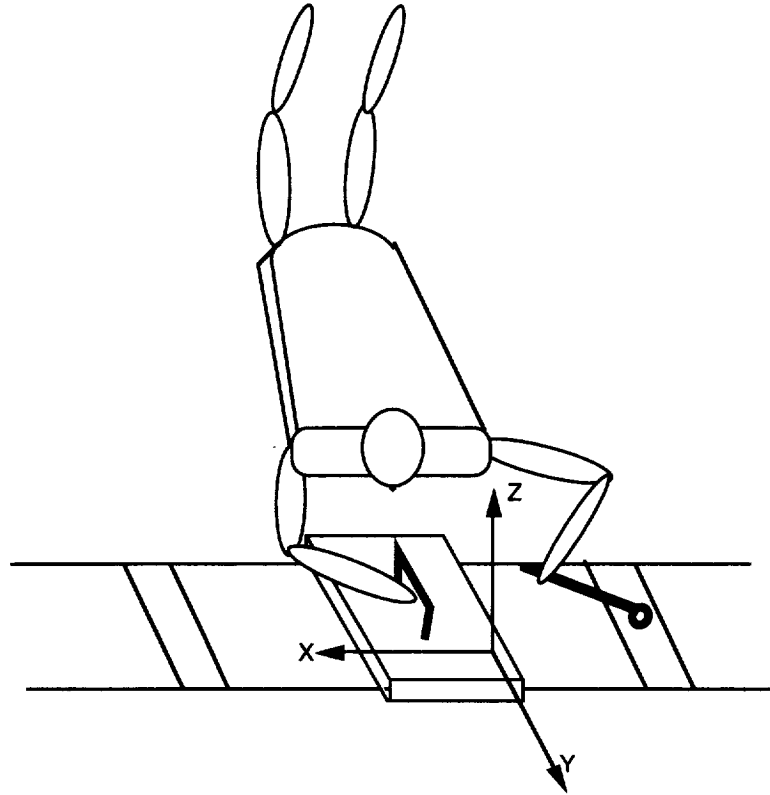
Figure 5. Sketch indicating the X, Y, and Z axes.

The experimental apparatus was mounted on the floor of the KC-135 aircraft (figure 4). Calibration tests were conducted in the laboratory prior to the flight. During the flight, prior to the start of the zero-gravity parabolic arcs, the subject donned the pressurized (4.3 psi) Shuttle Extravehicular Mobility Unit (EMU) with the help of suit technicians. At the onset of zero gravity, two assistants moved the subject into position for the designated task for that parabola.

The remainder of this document is divided into four sections, one for each of the tasks investigated.

3. MAXIMUM TORQUE TASK

3.1 Description of Task

The test subject was positioned facing the work surface. One hand held a wrench and applied a maximal isometric effort in a direction parallel to the mediolateral axis of his body. The other hand grasped an EVA handrail located 61 cm (24 in.) to the side (figure 1). A description of the EVA handrail can be found in the Appendix.

3.2 Methods

3.2.1 Experimental Procedures

The torque wrench was attached to the fixed bolt fitting, with the arm of the wrench parallel to the longitudinal axis of the subject's body (figure 1). The subject's non-test hand held onto the handrail mounted on the force platform. The subject was instructed to produce as much torque in the wrench as he could, holding the handle 24.8 cm (9.8 in.) from the end. He first rotated the torque wrench in one direction and held it there for several seconds; he then rotated the wrench in the opposite direction and held it there for several seconds. Force plate and torque wrench data were collected during the zero-gravity interval.

3.2.2 Experimental Design

A repeated measures design was used in this study. The independent variables included were the hand (dominant vs. non-dominant) and the direction in which the force was applied (inward vs. outward, or clockwise vs. counterclockwise). Each subject repeated the trials twice for each condition. The dependent variables included the three axial components of force, the three components of the moment, the resultant shear force, and the torque output from the wrench. Some trials were missed due to malfunctioning of the experimental tools and the lack of time for the subject to position himself properly. When there were extra parabolas, certain test conditions were repeated.

3.2.3 Data Treatment

Raw data were in the form of seven channels of time-based data for each parabola (three forces and three moments from the forceplate, and the torque from the torque wrench) for the duration of the zero-gravity interval. The window of data corresponding to the actual performance of the task was determined from plots of the data and from the video recordings. Within each window, the peak magnitude for each of the seven channels was obtained. Also, the two components of force parallel to the direction of movement (X and Y) were combined to calculate a resultant shear force and the peaks of these data were determined too. For comparison purposes, necessary manipulation of the data was performed to change the coordinate system from one based on the forceplate to one based on the subject.

3.2.4 Data Analysis

For each subject, there were from one to three trials of each test condition (hand and direction). Since this task required a maximal effort, the largest value for each of the eight dependent variables was taken as representative for that subject.

The results focused on eliciting the differences between the dominant and non-dominant hand, as well as between different directions of movement. The responses of each dependent variable to the test variables (side, direction) were first examined descriptively. Next, the dependent variables were tested for statistical significance using various statistical tests. A multivariate analysis of variance (MANOVA) was

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performed to determine the collective response of the dependent data to changes in each one of the test variables. The MANOVA was followed by an univariate analysis of variance (ANOVA) to determine the influence of all test variables and their interactions. Finally, the Ryan-Einot-Gabriel-Welsh test criterion was used to determine whether there were significant variations within the levels of each test variable. A significance level of 0.05 was chosen to determine whether the analyses were significant or not.

3.3 <u>Results</u>

Table 1 presents the group results for the various conditions. These data are presented graphically in the bar charts in figures 6 through 9 and are discussed in detail below.

Table 1. Averaged Subject Data for the Maximum Torque Task

<u>VARIABLE</u>	<u>LEFT - IN</u>	<u>LEFT - OUT</u>	<u>RIGHT - IN</u>	<u>RIGHT - OUT</u>
Peak Force X	209.8 (19.3)	170.2 (72.7)	236.1 (26.5)	172.3 (67.1)
Peak Force Y	110.7 (20.4)	98.5 (42.6)	90.0 (35.3)	68.2 (31.5)
Peak Force Z	90.4 (57.6)	51.2 (13.8)	65.7 (45.7)	65.8 (38.9)
Peak Shear Force	212.4 (16.4)	164.7 (78.0)	240.1 (24.8)	173.9 (66.8)
Angle at Peak Shear	19.4 (4.1)	22.6 (7.3)	11.9 (4.5)	9.4 (12.3)
Peak Moment X	18.2 (5.4)	8.8 (2.5)	15.1 (3.0)	10.9 (6.5)
Peak Moment Y	17.0 (1.9)	16.4 (8.3)	20.5 (2.0)	18.8 (11.8)
Peak Moment Z	29.7 (4.1)	15.0 (8.1)	28.7 (6.3)	14.2 (6.7)
Peak Torque	67.4 (10.0)	42.5 (13.0)	75.6 (18.3)	48.8 (22.1)

Note: Force values are in Newtons; moments and torques are in Newton-meters. Standard deviations are in parentheses. Values are the average of the six subjects' greatest efforts.

3.3.1 Torque

Figure 6 presents the maximum applied torque (in Newton-meters) from the MTT tests as measured by the instrumented torque wrench. The label under each bar indicates the test conditions: side and direction of rotation. "Left" and "Right" indicate the side that the subjects used to generate the torque with the wrench. "In" and "Out" indicate the direction of rotation, relative to the operator. An inward movement with the right arm was a clockwise rotation; outward was counterclockwise. Conversely, an inward movement with the left arm was a counterclockwise rotation; outward was clockwise.

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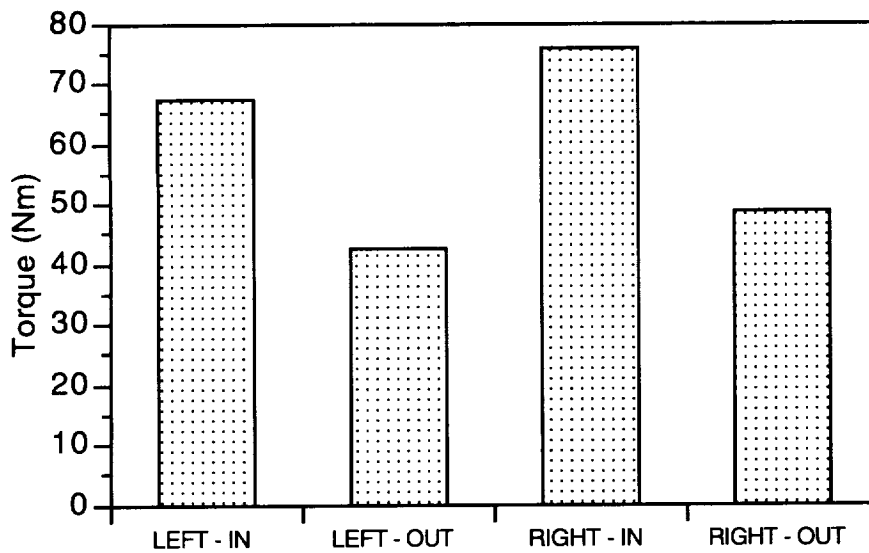
Figure 6. Peak applied torque during the maximum torque task.

3.3.2 Forces

Figure 7 shows the maximum component forces (in Newtons) applied by the supporting hand to the handrail, as well as the maximum resultant shear force. Note that the peak shear force was the maximum of the resultant calculated from the forces in the X-Y plane. Since the peak force X and the peak force Y may not have occurred simultaneously, the peak shear force cannot be calculated from the data given in the tables as peak force X and peak force Y.
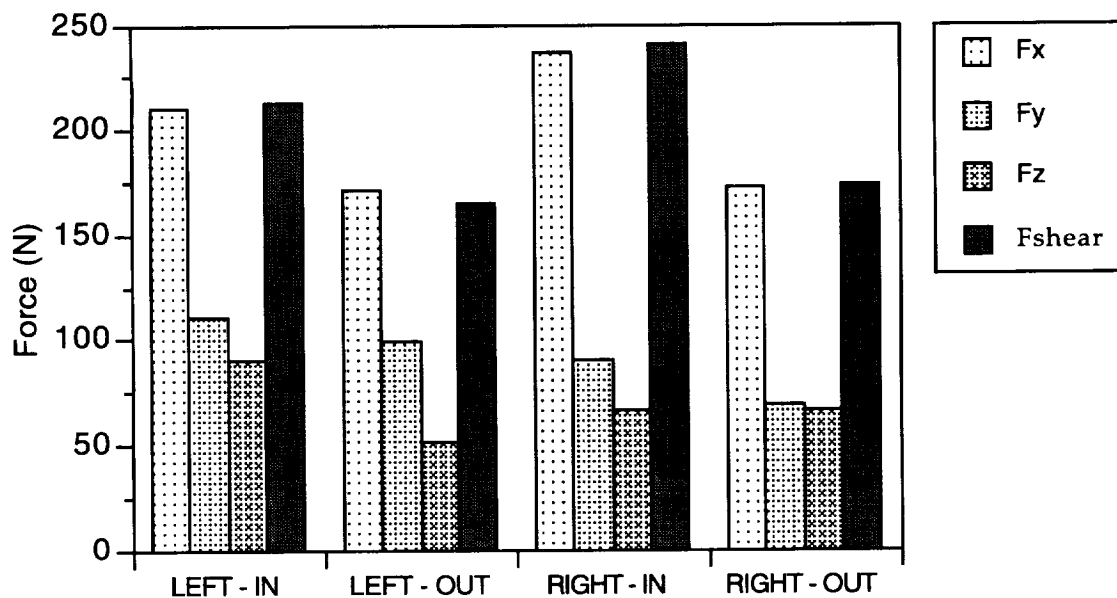
Figure 7. Peak component forces from the EVA handrail during the MTT.

The angles of the peak resultant shear forces are shown in figure 8. Angles are in degrees and are measured relative to the X-axis (mediolateral axis of subject's body).
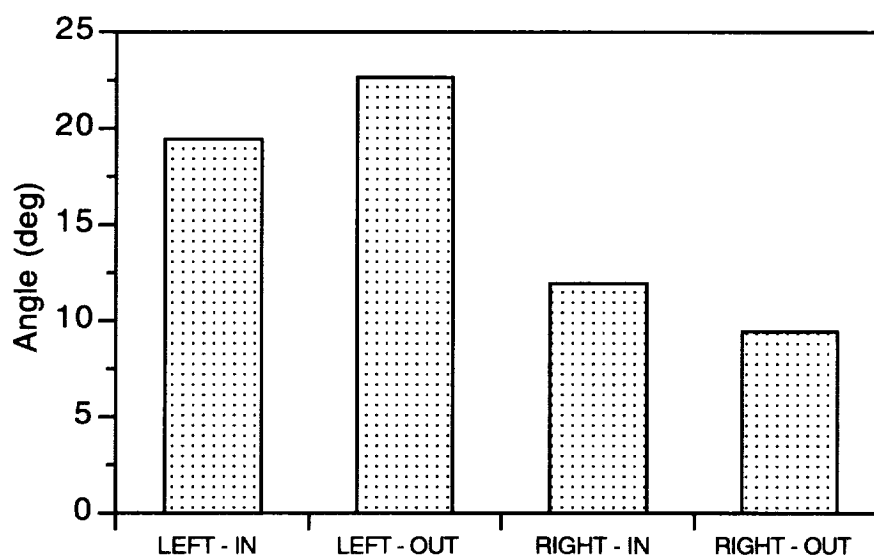
Figure 8. Angle at maximum shear force from the MTT.

3.3.3 Moments

Figure 9 presents the maximum of the X, Y, and Z moments (in N·m) applied by the hand holding the EVA handrail.
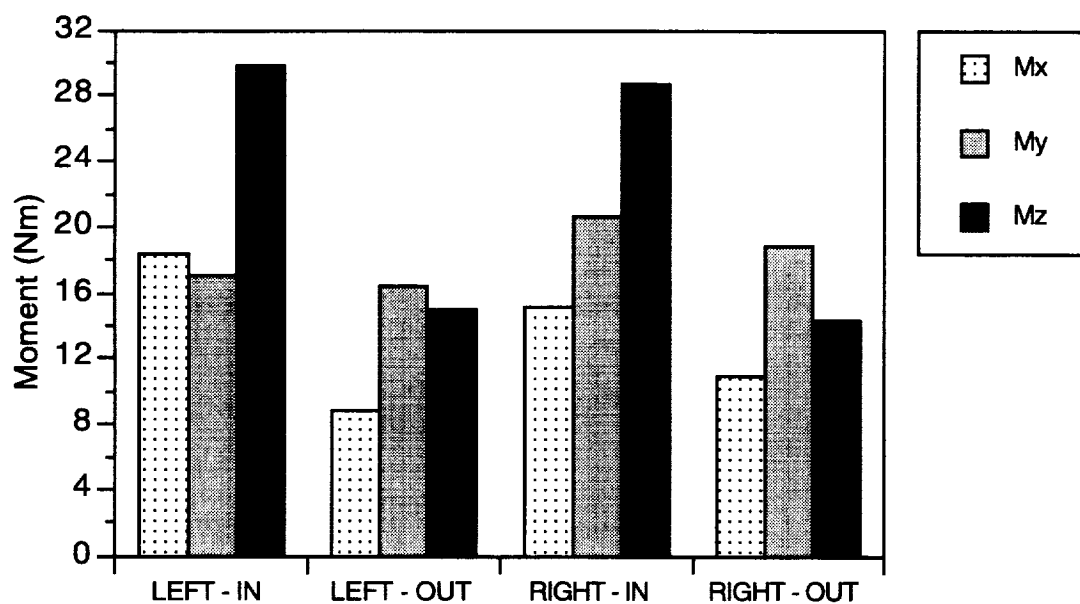
Figure 9. Peak component moments from the EVA handrail during MTT.

3.3.4 Statistical Analysis

Multivariate analyses on the data from the maximum torque task showed that the dependent measures as a whole were affected by a change in the direction ($F\{16,5\}$ = 13.01; $p < 0.005$) only. A change in the side (right vs. left) as well as the interaction between side and direction did not affect the dependent measure set significantly. Subsequent univariate analyses showed that none of the force components, moment components, resultant shear force, or torque output were significantly affected by a change in the side at a significance level of 0.05. However, the X force, X moment, Z moment, torque output, and resultant shear force were all significantly affected by a change in the direction. All of these variables were significantly greater during inward motion than during outward motion. There were no significant differences to the Y force and moment and the Z force between the inward and outward directions.

3.4 <u>Discussion</u>

For the MTT, the subjects generated more torque during inward rotations than during outward rotations. The greatest component forces were in the X direction, along the mediolateral axes of the subjects' bodies. This was expected since the X axis was the axis along which the force had to be applied to generate a torque with the wrench. Magnitudes of the X component of force were approximately 171 N for outward rotations and 223 N for inward rotations. The peak components of force in the Y and Z directions were relatively low and fairly consistent across the test conditions. The peak Y force, which was parallel to the operator longitudinally, ranged between 68 and 111 N. The peak Z force averaged around 68 N, about one-third of the maximum X-force. In contrast to these forces, the peak X force was significantly affected by the direction of rotation. Also, it appeared as if the subjects were applying the shear force at a greater angle with their left hands than with their right.

The peak Z moment was relatively greater than the X and Y moments during inward application of torque. Peak moments were greatest in the Y direction when performing outward rotations. The peak X moment and peak Z moment were significantly affected by the direction of rotation. The peak X and Z moments dropped by nearly 50% when the direction changed from inward to outward rotation. On an average, the peak Z moment dropped from 29 N·m to 16 N·m and the peak X moment dropped from 17 N·m to 10 N·m. The peak Y moment averaged about 18 N·m.

The shear force was also significantly higher during inward rotation than during outward rotation. The shear force averaged about 226 N and 169 N during inward and outward rotations, respectively. Finally, the maximum amount of torque exerted by the subjects was about 72 N·m during inward rotation and about 46 N·m during outward rotation.

A major limitation of this study was the small number of subjects due to limited access to the zero-gravity environment on the KC-135 aircraft. Because of this, care had to be taken in reviewing the results. Perhaps with a larger sample size, additional statistical differences would have been noted.

4. ENDURANCE TASK

4.1 Description of Task

The operator applied a sustained effort with a wrench in an angular direction parallel to the plane of his body. The other hand grasped an EVA handrail. The moment arm was held constant at 10.2 cm (4 in.). The task was similar to that of the MTT task.

4.2 Methods

4.2.1 Experimental Procedures

Two different protocols were used for this task. For the first two subjects, the torque wrench was attached to the spring-loaded bolt fitting. The subject was instructed to rotate the wrench attached to the tool fitting to a 45° angle and hold it there for several seconds. He used the handle 10.2 cm (4 in.) from the end of the wrench. His non-test hand held on to the handrail mounted on the force platform. For these first two subjects, the spring mechanism did not function according to plans and could only be used for clockwise rotations.

For the remaining four subjects, the task was modified. The endurance task (ET) used the same fixed bolt fitting as the MTT. Essentially, the task became identical to the MTT except that a 10.2 cm moment arm was used to apply the torque rather than 25.4 cm.

With both protocols, forceplate and torque wrench data were collected during the entire zero-gravity duration. Within each parabola the task was performed at least twice, once for each direction.

4.2.2 Experimental Design

The independent variables for this task were the hands (dominant vs. non-dominant), and the directions in which the force was applied (inward vs. outward rotation). Each subject repeated the trials twice for each hand and for each task. The dependent variables included the three components of force, the three components of moment, and the torque output from the wrench.

Each subject performed approximately two trials of each test condition, a test condition being one of the four combinations of hand and direction. Some trials were missed due to malfunctioning of the experimental tools and the lack of time for the subject to position himself properly. When time was available, missed test conditions were repeated.

4.2.3 Data Treatment

Raw data were in the form of seven channels of time-based data for each parabola (three forces and three moments from the forceplate, and the torque from the torque wrench) for the duration of the zero-gravity interval. The window of data corresponding to the actual performance of the task was determined from plots of the data and from the video recordings. Within each window, the peak magnitude for each of the seven channels was obtained. For comparison purposes, necessary manipulation of the data was performed in order to change the coordinate system from one based on the forceplate to one based on the subject.

4.2.4 Data Analysis

For the ET, in which the goal was to determine nominal loads while the task was performed, the average of the multiple trials was taken as representative for each subject. The results focused on eliciting the differences between the dominant and non-dominant hand, as well as between different directions of movement. Under each task condition, the responses of each dependent variable to the test variables (side, direction) were first examined descriptively. Next, the dependent variables were tested for statistical significance using various statistical tests. A MANOVA was performed to determine the collective response of the dependent data to changes in each one of the test variables. The MANOVA was followed by an univariate ANOVA to determine the influence of all test variables and their interactions. Finally, the Ryan-Einot-Gabriel-Welsh test criterion was used to determine whether there were significant variations within the levels of each test variable. A significance level of 0.05 was chosen to determine whether the analyses were significant or not.

4.3 <u>Results</u>

Table 2 presents the group results from the ET conditions. These data are presented graphically in the bar charts in figures 10 through 12.

4.3.1 Torque

Figure 10 presents the maximum applied torque (in N·m) from the ET tests as measured by the instrumented torque wrench. The label under each bar indicates the test conditions: side and direction of rotation. "Left" and "Right" indicate the side that was used to generate the torque with the wrench. "In" and "Out" indicate the direction of rotation, relative to the operator. An inward movement with the right arm was a clockwise rotation; outward was counterclockwise. Similarly, an inward movement with the left arm was a counterclockwise rotation; outward was clockwise.

Table 2. Averaged Subject Data for Endurance Task

VARIABLE	LEFT - IN	LEFT - OUT	RIGHT - IN	RIGHT - OUT
Peak Force X	211.7 (33.7)	151.6 (54.6)	222.8 (43.2)	153.2 (76.7)
Peak Force Y	54.1 (20.6)	51.4 (22.3)	48.7 (23.6)	34.2 (22.5)
Peak Force Z	57.2 (26.9)	33.4 (12.9)	53.8 (46.7)	35.2 (17.1)
Peak Moment X	9.5 (3.7)	6.3 (1.4)	8.8 (2.2)	5.0 (2.7)
Peak Moment Y	19.4 (3.7)	14.9 (7.0)	20.2 (3.8)	13.8 (8.0)
Peak Moment Z	20.6 (6.6)	10.1 (9.2)	19.3 (6.5)	9.1 (5.6)
Peak Torque	31.6 (4.4)	18.5 (4.8)	32.3 (7.3)	19.0 (9.4)

Note: Force values are in Newtons; moments and torques are in Newton-meters. Standard deviations are in parentheses. Values are the average of the six subjects' average peak efforts.
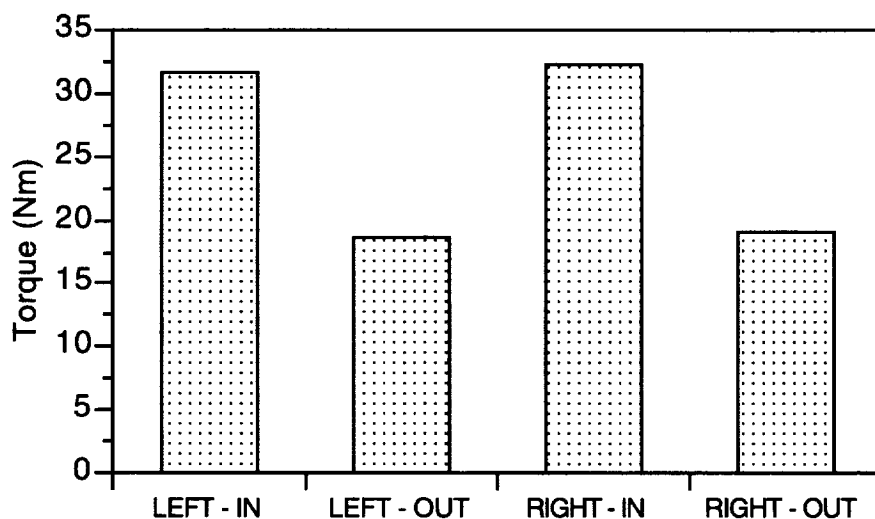
Figure 10. Peak torque during the endurance task.

4.3.2 Forces

Figure 11 presents the maximum component forces (in Newtons) applied by the supporting hand to the handrail.
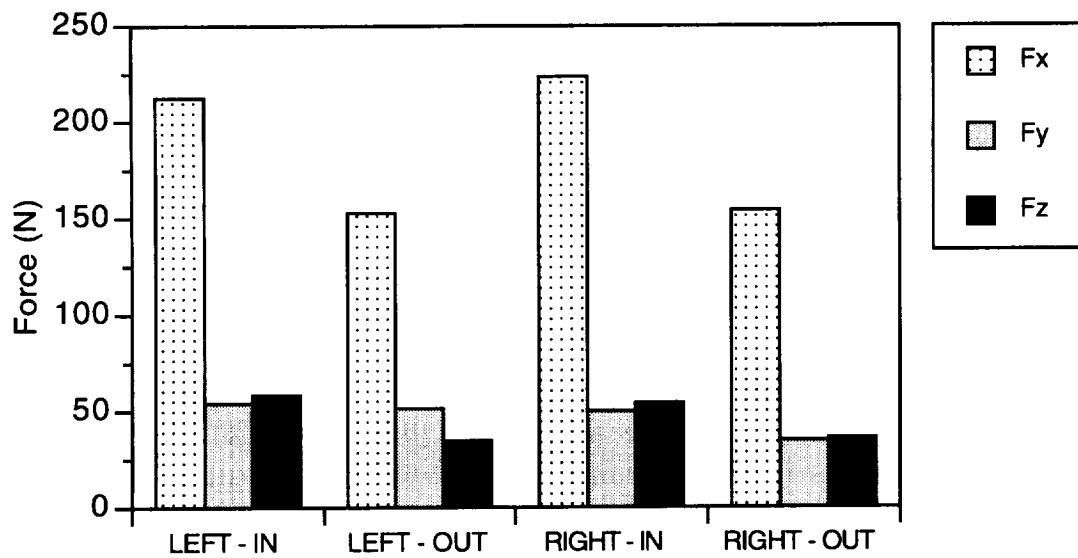
Figure 11. Peak component forces from the EVA handrail during the ET.

4.3.3 Moments

Figure 12 presents the maximum X, Y, and Z components of the handrail moments (in N·m) during the ET.
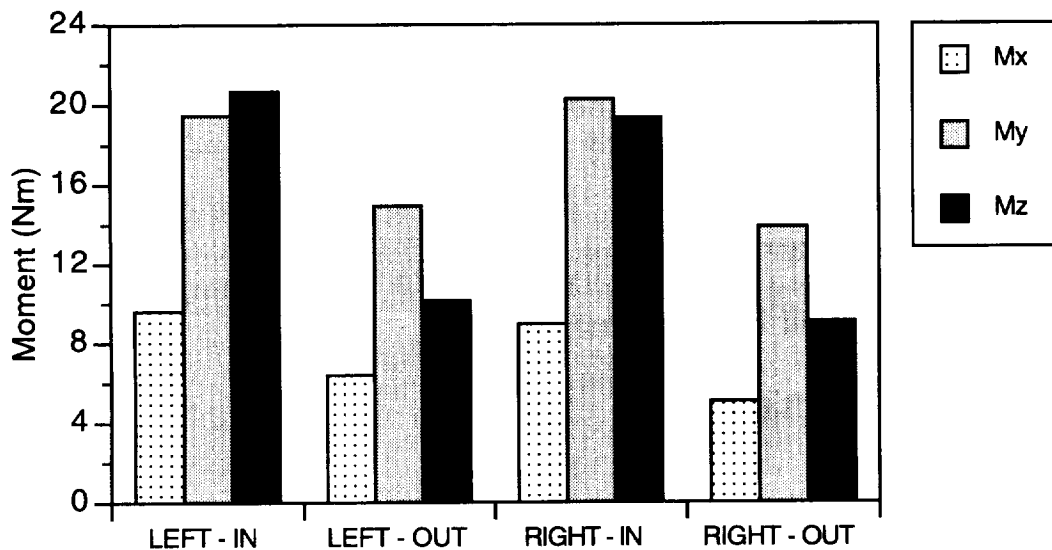
Figure 12. Peak component moments from the EVA handrail during the ET.

4.3.4 Statistical Analysis

Multivariate analyses on the data from the endurance task showed that the dependent measures as a whole were affected by a change in the direction ($F\{14,4\} = 17.99$; $p < 0.005$) only. A change in the side (right vs. left) as well as the interaction between side and direction did not affect the dependent measure set significantly. Subsequent

univariate analyses showed that none of the force components, moment components, or peak torque were significantly affected by a change in the side at a significance level of 0.05. However, the X force, Z force, X moment, Z moment, and the peak torque were all significantly affected by a change in the direction. All of these variables were significantly greater during inward motion than during outward motion. With regard to the Y force and Y moment, there were no significant differences between inward and outward directions.

4.4 Discussion

Many of the results from the ET were similar to that of the MTT. Initially, the ET was intended to limit the maximum possible torque to a preset limit (34 N·m) by using a spring-loaded bolt. This would have permitted observing the endurance characteristics of the subjects. However, due to the difficulties encountered during the test, the ET was reduced essentially to another MTT with a smaller moment arm.

The amount of torque produced by the subjects was significantly higher during inward rotation than during outward rotation. The torque was approximately 32 N·m during inward rotation and about 19 N·m during outward rotation. The effect of hand dominance was not significant, similar to the results from the MTT. It was also observed that the torque during the ET was about 50% lower than during the MTTs. This was primarily a result of the 60% reduction in the moment arm.

The peak force in the Y direction remained relatively constant across the conditions and ranged between 34 N and 64 N (table 2). No significant changes were observed across hand conditions. The peak Z force and the peak X force were significantly affected by a change in the direction. The peak Z force increased by about 21 N (60%) when the direction changed to inward and the peak X force increase by about 65 N. Both the X and Z peak forces were nearly constant across hand conditions.

A major limitation of this study was the small number of subjects due to limited access to the zero-gravity environment on the KC-135 aircraft. Because of this, care had to be taken in reviewing the results. Perhaps with a larger sample size, additional statistical differences would have been noted.

5. HANDRAIL PUSH/PULL TASK

5.1 Description of Task

The operator was positioned facing the work surface. He applied a maximal force on an EVA handrail, in a direction normal to the work surface. His other hand grasped another EVA handrail nearby. Figure 2 shows the task condition.

5.2 Methods

5.2.1 Experimental Procedures

For the HPPT, the subject grasped the EVA handrail on the forceplate with his test hand. The other hand provided stabilization by grasping the other EVA handrail. See figure 2 for a picture of the experimental arrangement. The subject was instructed to pull as hard as he could away from the forceplate for several seconds and push as hard as he could into the forceplate (not necessarily in that order). Force plate data were collected during the zero-gravity interval.

5.2.2 Experimental Design

A repeated measures design was used in this study. The independent variables were the hands (dominant vs. non-dominant) and the directions in which the force was applied (push vs. pull). Each subject repeated the trials twice for each hand and for each task. The dependent variables included the three axial components of force and the three components of the moment.

Each subject performed approximately two trials of each test condition, a test condition being one of the four combinations of hand and direction. Some trials were missed due to a lack of time for the subject to position himself properly. When time was available, missed test conditions were repeated.

5.2.3 Data Treatment

Raw data were in the form of six channels of time-based data for each parabola (three forces and three moments from the forceplate) for the duration of the zero-gravity interval. The window of data corresponding to the actual performance of the task was determined from plots of the data and from the video recordings. Within each window, the peak magnitude for each of the six channels was obtained.

For comparison purposes, necessary manipulation of the data was performed in order to change the coordinate system from one based on the forceplate to one based on the subject.

5.2.4 Data Analysis

For each subject, there were from one to three trials of each test condition (hand and direction). Since this task required a maximal effort, the largest value for each of six dependent variables was taken as representative for that subject.

The results focused on eliciting the differences between the dominant and non-dominant hand, as well as between different directions of movement. The responses of each dependent variable to the test variables (side, direction) were first examined descriptively. Next, the dependent variables were tested for statistical significance using various statistical tests. A MANOVA was performed to determine the collective response of the dependent data to changes in each one of the test variables. The MANOVA was followed by a univariate ANOVA to determine the influence of all test variables and their interactions. Finally, the Ryan-Einot-Gabriel-Welsh test criterion was used to determine whether there were significant variations within the levels of each test variable. A significance level of 0.05 was chosen to determine whether the analyses were significant or not.

5.3 Results

Table 3 and figures 13 and 14 present the group results from the HPPT conditions. Due to difficulties in data collection, data from only five of the six subjects were used to calculate the averages from the right side.

Table 3. Averaged Subject Data for Handrail Push/Pull Task

VARIABLE	LEFT - PULL	LEFT - PUSH	RIGHT - PULL	RIGHT - PUSH
Peak Force X	156.1 (62.4)	132.8 (47.5)	138.2 (122.2)	129.4 (26.7)
Peak Force Y	63.9 (23.6)	44.6 (12.8)	78.5 (10.0)	76.8 (25.5)
Peak Force Z	125.9 (34.9)	134.5 (41.9)	104.5 (11.8)	160.1 (50.7)
Peak Moment X	11.7 (5.2)	12.5 (4.5)	12.9 (7.1)	11.4 (4.6)
Peak Moment Y	13.5 (6.3)	12.0 (4.3)	11.4 (12.3)	11.6 (2.1)
Peak Moment Z	8.3 (3.4)	7.4 (3.7)	8.8 (7.0)	7.6 (4.0)

Note: Force values are in Newtons; moments are in Newton-meters. Standard deviations are listed in parentheses. Values are the average of the subjects' greatest efforts.

5.3.1 Forces

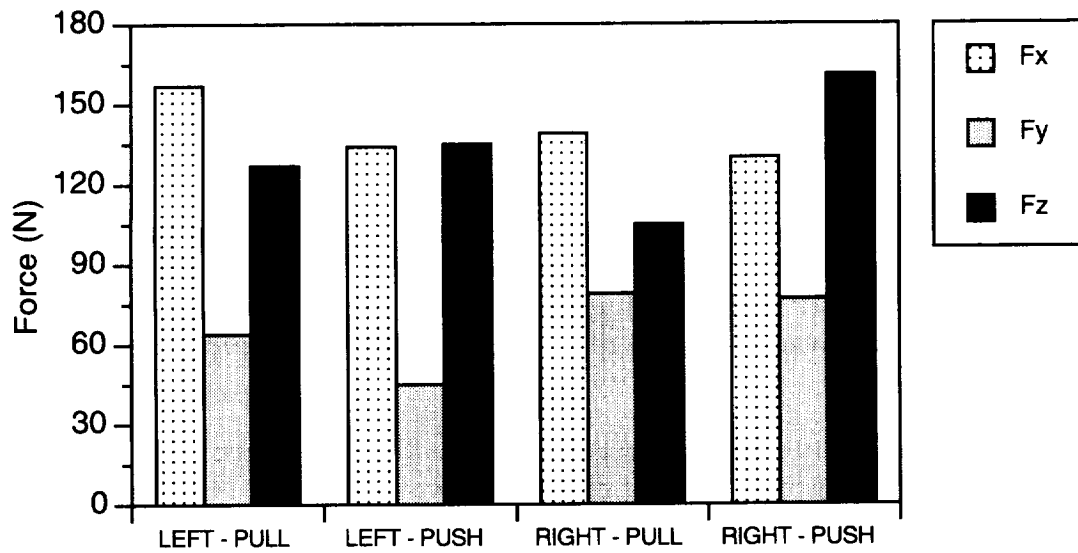Figure 13 presents the component forces from the HPPT.

Figure 13. Peak component forces during handrail push/pull task.

5.3.2 Moments

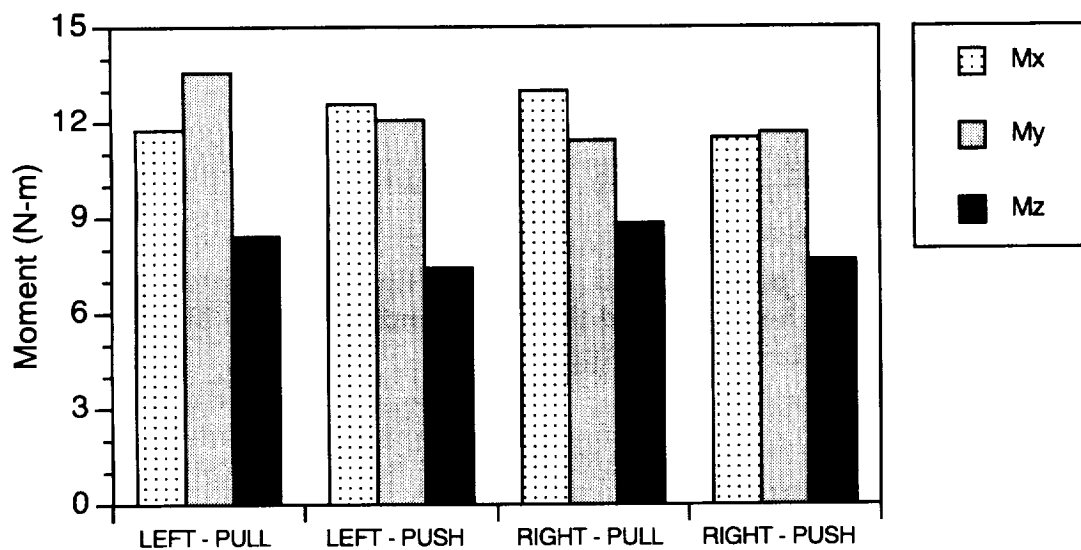Figure 14 presents the maximum components of moments during the HPPT.

Figure 14. Peak component moments from the handrail push/pull task.

5.3.3 Statistical Analysis

Multivariate analyses on the data from the HPPT revealed that none of the test conditions affected the dependent measure set significantly. Subsequent univariate ANOVAs also showed that none of the dependent measures, with the exception of the Y force, varied significantly as a function of the side or the direction. The Y force was significantly higher with the right hand than with the left hand ($p < 0.05$).

5.4 Discussion

Recall that the purpose of the HPPT was to generate a maximal amount of force in the direction normal to the work surface. The subjects seemed to have difficulty performing this task. The only method for generating a force normal to the surface (Z-direction) with one hand was to tilt the body with respect to the supporting hand (figure 3).

The peak force in the X direction was usually greater than the force in the Z direction. The average peak X force across the test conditions was about 139 N and the average peak Z force was about 131 N.

The Y force was significantly greater with the right hand than with the left hand. The average Y force with the right hand was about 78 N and with the left hand was 54 N (30%). The X, Y, and Z moments showed no significant trends across different hands as well as across push and pull conditions. The X and Y moments averaged 12.2 N·m and the Z moment averaged 8.1 N·m.

A major limitation of this study was the small number of subjects due to limited access to the zero-gravity environment on the KC-135 aircraft. Because of this, care had to be taken in reviewing the results. With a larger sample size, additional statistical differences would most likely have been noted.

6. POWER TOOL TASK

6.1 Description of Task

The operator used the HST power tool to loosen and tighten bolt fasteners. One hand held the tool and the other hand grasped the EVA handrail (figure 3). A description of the HST power tool can be found in Appendix A.

6.2 Methods

6.2.1 Experimental Procedures

For the PTT, the subject was handed the power tool that had already been set for the direction of rotation for that parabola. His other hand grasped the handrail attached to the force platform.

The subject attempted to engage the tool on the bolt fixture. Once the tool was engaged, he turned it on and tightened or loosened the bolt for a couple of seconds (figure 3). Force plate data were collected during the zero-gravity interval.

6.2.2 Experimental Design

A repeated measures design was used in this study. The independent variables were the hands (dominant vs. non dominant), and the direction of rotation of the tool (tighten vs. loosen). Each subject repeated the trials twice for each hand and for each task. The dependent variables included the three components of force and the three components of the moment from the handrail.

Each subject performed about two trials of each test condition, a test condition being one of the four combinations of hand and direction. Some trials were missed due to experimental tools malfunctioning and the lack of time for the subject to position himself properly. When time was available, missed test conditions were repeated.

6.2.3 Data Treatment

Raw data were in the form of six channels of time-based data for each parabola (three forces and three moments from the forceplate) for the duration of the zero-gravity interval. The window of data corresponding to the actual performance of the task was determined from plots of the data and from the video recordings. Within each window, the peak magnitude for each of the six channels was obtained. For comparison purposes, necessary manipulation of the data was performed in order to change the coordinate system from one based on the forceplate to one based on the subject.

6.2.4 Data Analysis

For this task, in which the goal was to determine nominal loads while the task was performed, the average of the multiple trials was taken as representative for each subject. The results focused on eliciting the differences between the dominant and non-dominant hand, as well as between different directions of rotation of the tool.

6.3 **Results**

Unlike the other three tasks, the PTT was very difficult to perform in the simulated zero-gravity environment. This was primarily due to the lack of time for the subjects to position themselves in front of the test site and to position the tool on the bolt. In addition, it was difficult for the subjects to prevent rotation of their bodies while using the tool. Thus many of the trials of this task did not result in useful data.

Table 4 summarizes the test results. The row labeled N indicates the number of subjects who provided quantitative data for calculating the average values. The peak component forces and moments from the available PTT data are shown in figures 15 and 16, respectively.

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Table 4. Averaged Subject Data for Power Tool Task

VARIABLE	LEFT LOOSEN	LEFT TIGHTEN	RIGHT LOOSEN	RIGHT TIGHTEN
N	3	4	2	1
Peak Force X	64.1 (47.2)	31.2 (1.3)	75.9 (12.8)	34.9
Peak Force Y	61.4 (34.7)	44.4 (18.3)	64.5 (36.6)	11.8
Peak Force Z	62.4 (12.7)	53.1 (16.7)	82.5 (33.6)	44.9
Peak Moment X	5.9 (5.3)	7.4 (3.5)	5.8 (0.1)	3.6
Peak Moment Y	5.8 (3.8)	11.1 (3.9)	18.7 (14.6)	6.2
Peak Moment Z	5.9 (6.9)	8.1 (3.6)	6.6 (3.8)	0.5

Note: Force values are in Newtons; moments are in Newton-meters. Standard deviations are listed in parentheses. Values are the average of the N subjects' average efforts.
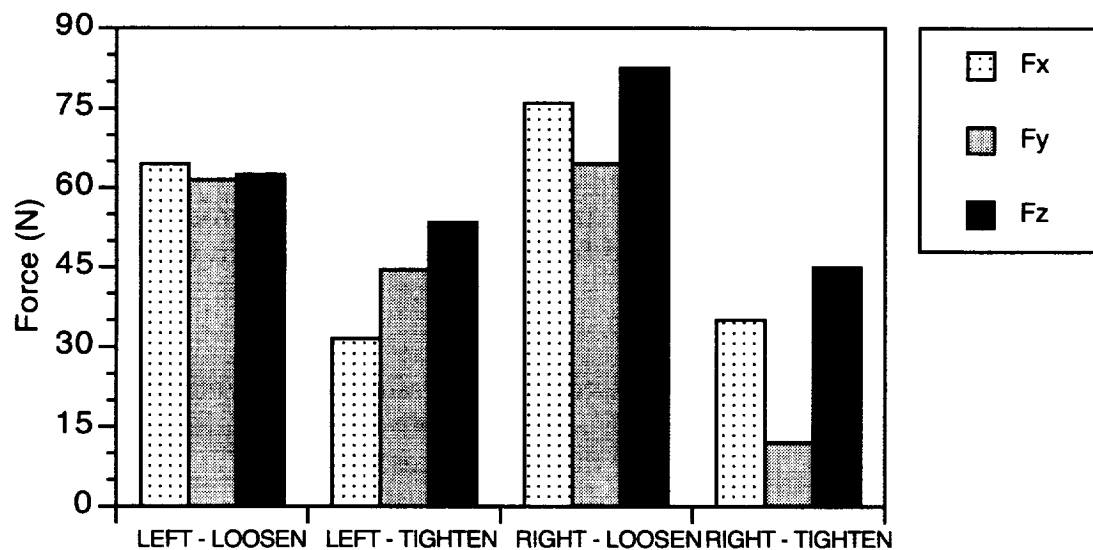

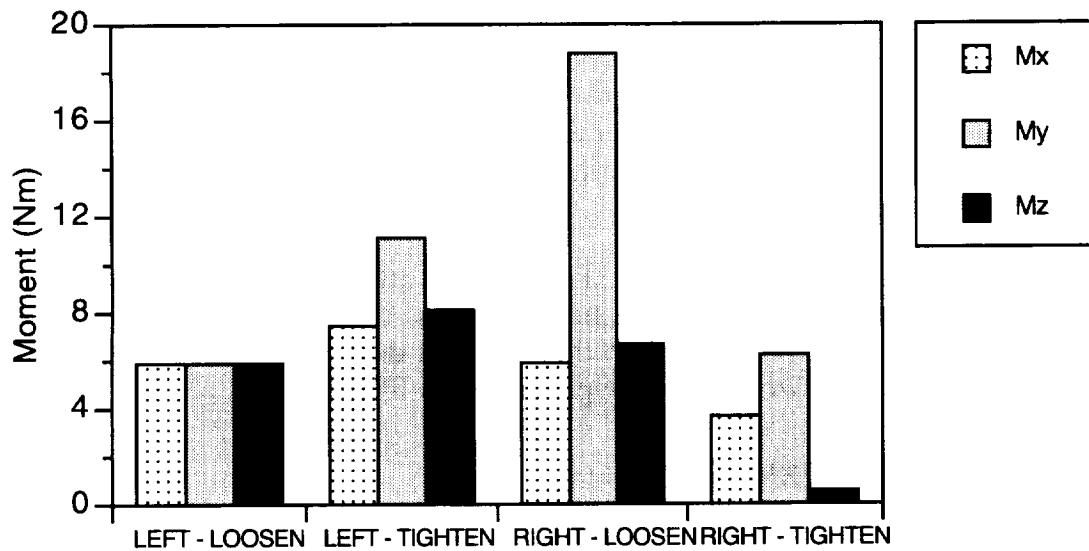Figure 15. Peak component forces during power tool task.

Figure 16. Peak component moments from power tool task.

Since not all conditions were performed by the subjects, only inferences were drawn from the results. No statistical analyses were performed.

6.4 Discussion

As mentioned, it was difficult to perform analyses on the PTT data. The time available during each parabola was insufficient to complete the tasks. Unlike the other three tasks, subjects had to position themselves away from the worksite, since they had to hold the tool between the worksite and themselves. This might have decreased the subjects' stability. In addition, the power tool was awkward to hold as compared to the wrench that was used during the maximum torque and endurance tasks.

7. CONCLUSIONS

The primary objectives of this study were to determine the amount of torque that can be produced by a suited operator in zero gravity without the use of foot restraints and to measure the loads transmitted via the supporting hand to the EVA handrail and the supporting structure. In addition, it was also intended to document any differences that may exist while using different hands and while performing the task in different directions. Finally, the study also examined the feasibility of using a power tool to loosen and tighten fasteners.

It was seen that these subjects could produce as much as 75 N·m of torque using a tool with a moment arm of 25 cm. While doing so, loads on the supporting hand were over 100 N in the direction normal to the work surface and 200 N in a tangential direction. No differences in strength capabilities between the left and right hands were noticed. The subjects were able to exert more torque when they were rotating the tool inward. This indicates an important aspect of how to perform EVA

operations: to maximize the effort and perform a task more effectively, suited crewmembers should be trained to position themselves so that their hand operation results in inward rotation. This increased effort with inward rotation or decreased effort with outward rotation can be best utilized in a zero-gravity environment if other equipment does not restrict the crewmember's position. This should be considered when designing a work space.

The power tool was very difficult to use. For efficient use of this tool, it may be necessary to redesign it in such a way that the subjects could still keep their bodies close to the work site. Hence, it is recommended that the tool designers should conduct ergonomic evaluations to optimize the use of power tools in space.

8. FUTURE RECOMMENDATIONS

It is recommended that future tests of this nature should be conducted in zero gravity without the suit on to document the strength decrements that occur while wearing a pressurized suit. It is also suggested that trials be conducted using PFRs so that we can determine the benefits and/or disadvantages of performing these tasks with and without the foot restraints. Finally, it is recommended that the tool designers should conduct ergonomic evaluations in order to optimize the use of power tools in space.

APPENDIX A

HANDRAIL, EVA

S88-32969
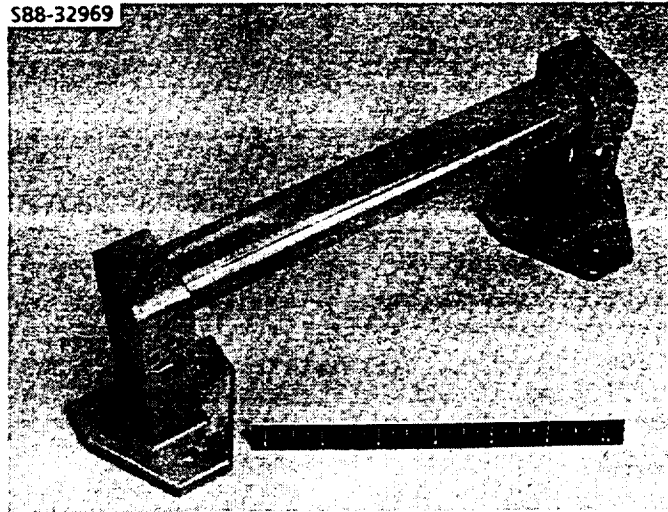
OVERVIEW

The EVA handrail is an assembly of a left- and right-hand standoff bracket and tubing, designed to allow crewmember translation and restraint along a variety of structures. A middle bracket is incorporated into the design when additional structural support is required. Handrails are used at various points in the Orbiter cargo bay, on tool containers, and on satellites as a transfer aid, stabilizer, and tether point. All EVA handrails are painted yellow for easy visual identification.

OPERATIONAL COMMENTS

Many different EVA handrails have been used in the Space Shuttle EVA program. This particular handrail represents one of the better examples of handrail design. It is included in this document as a recommended standard handrail for any application. The Hubble Space Telescope (HST) tool box uses this handrail. Some of its features include:

1. The handrail tubing can be cut to measure and is secured at the desired points by the brackets.
2. Hooks and end effectors can be attached over the standard cross-section tubing.
3. Tether points have been integrated into the standoff brackets.
4. Damaged tubing and brackets are easily replaceable.

For more detailed information on handrail design criteria, refer to NSTS 07700, vol. XIV, appendix 7, Description and Design Requirements - EVA.

CONTACTS

Operational: R. C. Trevino, NASA/DF42, (713) 483-2597
Technical: R. J. Marak, NASA/EC5, (713) 483-9144
Source: M. Withey, ILC Space Systems, (713) 488-9080

HANDRAIL, EVA

Technical Information			
Part number	Tube	10174-20036-01	9.72 in.
		10174-20036-02	14.98 in.
		10174-20036-03	19.72 in.
		10174-20036-04	25.97 in.
		10174-20036-05	32.77 in.
		10174-20036-06	51.22 in.
		10174-20036-07	61.01 in.
	Bracket	10174-20023-01	Right-hand
		10174-20023-02	Left-hand
		10174-20023-03	Middle
Weight	Tube	10174-20036-01	0.19 lb
		10174-20036-02	0.29 lb
		10174-20036-03	0.38 lb
		10174-20036-04	0.50 lb
		10174-20036-05	0.63 lb
		10174-20036-06	0.98 lb
		10174-20036-07	1.16 lb
	Bracket	10174-20023-01	0.54 lb
		10174-20023-02	0.54 lb
		10174-20023-03	0.48 lb
Material/ construction	Aluminum		
Temperature range	-150° to +250° F (operational)		
Availability	Flight specific		

Dimensional Data	
A	4.100 in.
B	1.000 in.
C	2.000 in.
D	0.500 in.
E	1.625 in.
F	2.630 in.
G	3.000 in.
H	1.380 in.
I	0.750 in.
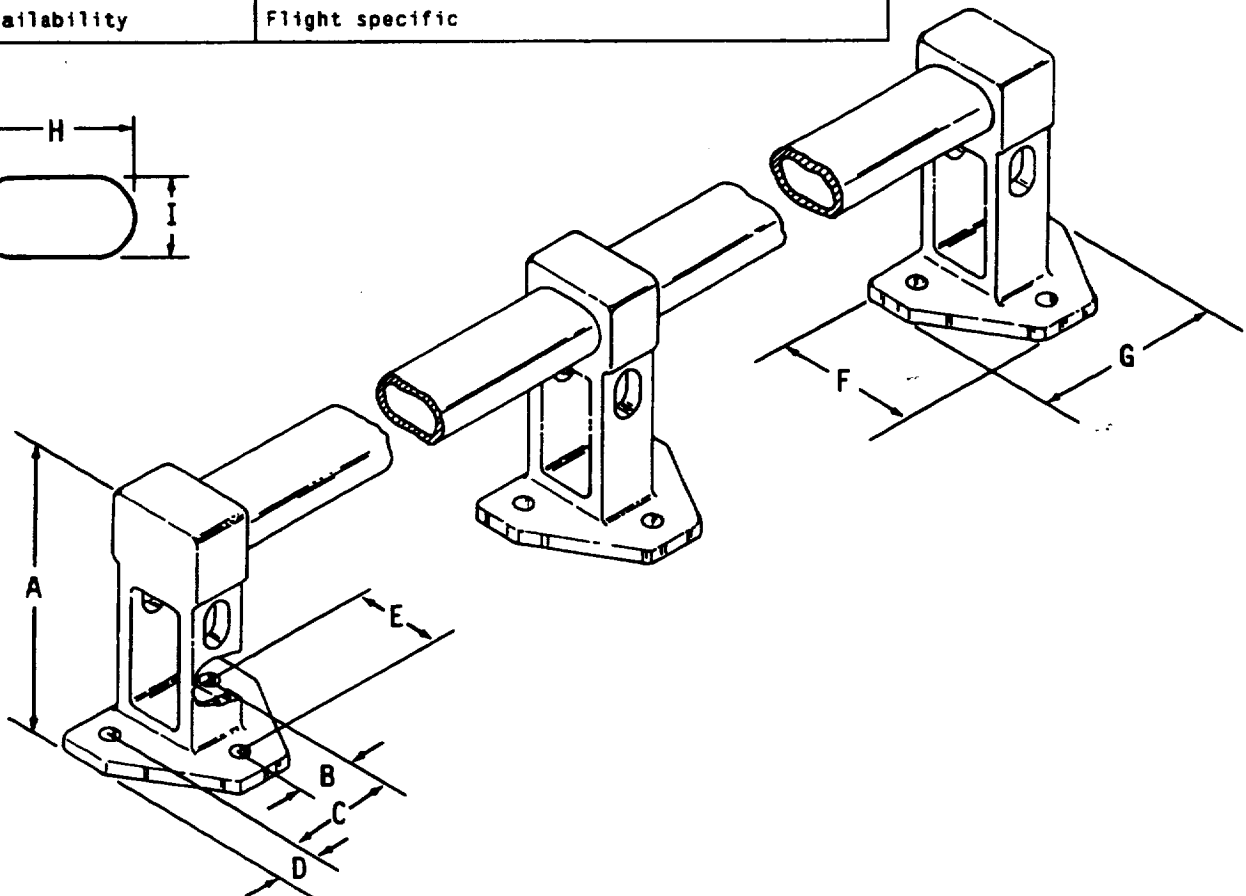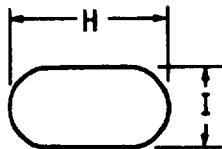
POWER TOOL, EVA (HST)
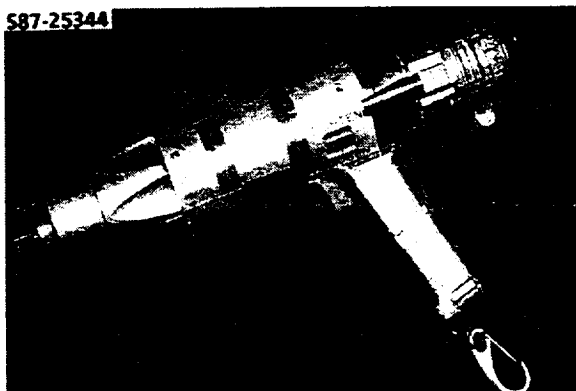
OVERVIEW

This EVA power tool is a modified, battery-operated power tool with torque and rpm control. The clutch torque is controlled by use of a serrated adjustment ring. The design includes a 3/8-inch drive drop-proof tether fitting, forward and reverse drive rotation, torque ranges from 50 to 300 in-lb in four clutch positions, a bayonet fitting which allows attachment of the tool to the mini work station, a tether point on the removable battery pack, and a 6-foot retracting tether with a french hook in the tool handle. This tool was developed for use in Hubble Space Telescope (HST) maintenance.

OPERATIONAL COMMENTS

The crewmember has three choices to make in the operation of this tool: torque limit, direction, and rpm. The crewmember selects torque by setting the clutch ring. Forward or reverse rotation is selected by setting the tighten/loosen switch. The tool has fixed speeds of 20 and 60 rpm which are controlled by a switch on the side of the tool opposite the tighten/loosen switch. The motor is engaged by pulling back on the trigger-style control switch in the handle. Releasing the control switch disengages the motor. The tool direction switch should be returned to the OFF position when it is not in use. The tool uses a replaceable/rechargeable 7.2 volts dc nickel-cadmium battery pack. The battery pack life is dependent on the duration and loads that it will see. The EVA power tool and its battery packs are usually stored in a middeck locker for launch. The tool can be stored in the payload bay in a tool container, but without the battery packs.
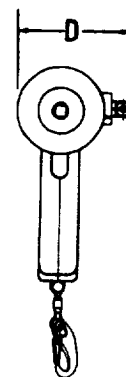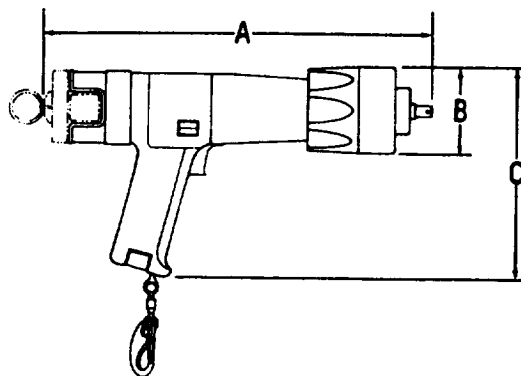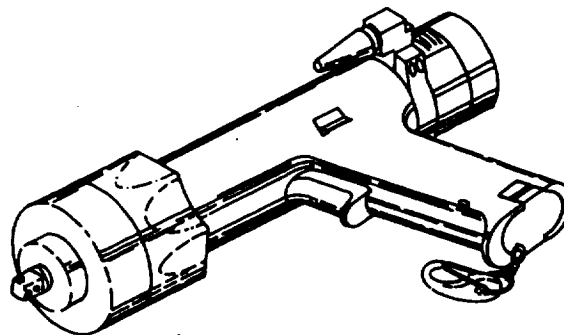
CONTACTS

Operational: S. Boyd, NASA/DF42, (713) 483-1755
Technical: R. J. Marak, NASA/EC5, (713) 483-9144
Source: M. Withey, ILC Space Systems, (713) 488-9080

POWER TOOL, EVA (HST)

Technical Information	
Part number	10181-10001-01 without Velcro 10181-10001-02 with Velcro
Weight	3.40 lb (without battery)
Material/ construction	Body: Glass-filled Lexan Reflective aluminum tape
Temperature range	-150° to +250° F
Lubricants used	Fluorinated polyester Vacuumized grease
Power source	7.2 V rechargeable Ni-Cd battery pack
Speed	20 rpm, 60 rpm (with low torque loads)

Stall torque values
(in-lb)
	Position Tighten/Loosen
	Low speed 1 48
	             2 85
	             3 128
	             4 160
	
	High speed 1 29
	             2 66
	             3 177
	             4 298

No. fasteners per
battery charge
	48 - LO speed, no. 8 screws, 1/2-inch length,
	     fine threads
	44 - HI speed, 1/4-inch screws, 1/2-inch length,
	     fine threads

Availability	Flight specific

Dimensional Data	
A	12.20 in.
B	2.75 in.
C	6.70 in.
D	3.63 in.

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Sudhakar L. Rajulu*, Jeffrey Poliner*, and Glenn Klute

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NASA Johnson Space Center
Houston, Texas 77058

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13. ABSTRACT *(Maximum 200 words)*
With an increase in the frequency of extravehicular activities (EVAs) aboard the Space Shuttle, NASA is interested in determining the capabilities of suited astronauts while performing manual tasks during an EVA, in particular the situations in which portable foot restraints are not used to stabilize the astronauts. Efforts were made to document the forces that are transmitted to spacecraft while pushing and pulling an object as well as while operating a standard wrench and an automatic power tool. The six subjects studied aboard the KC-135 reduced gravity aircraft were asked to exert a maximum torque and to maintain a constant level of torque with a wrench, to push and pull an EVA handrail, and to operate an HST power tool.

The results of this study give an estimate of the forces and moments that an operator will transmit to the handrail as well as to the supporting structure. In general, it was more effective to use the tool inwardly toward the body rather than away from the body. There were no differences in terms of strength capabilities between right and left hands. The power tool was difficult to use. It is suggested that ergonomic redesigning of the power tool may increase the efficiency of power tool use.

14. SUBJECT TERMS
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